IRRIGATION STUDIES WITH MARSH GRAPEFRUIT

By

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA
June, 1955

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ACKNOWLEDGMENTS

The author wishes to express his sincere thanks to Apshawa Groves, Inc., Clermont, Florida, for assistance which made this research possible. He is indebted to Dr. Werner Husmann, General Manager, for his many acts of assistance, helpful criticism, and kindness, and to Messrs. A. N. Fox and George Sanders of his organization for their courtesies.

He is deeply grateful to Dr. H. S. Wolfe, Head Professor of Horticulture, University of Florida, for his counsel throughout the course of the work. Appreciation is extended to Dr. L. C. Hammond, Assistant Professor of Soils; Dr. J. H. Davis, Professor of Botany; Dr. G. J. Stout, Professor of Horticulture; Mr. Zach Savage, Agricultural Economist; and Dr. W. D. Hanson, formerly Assistant Professor of Agronomy (now Head, Biometrics Unit, U. S. Department of Agriculture, Plant Industries Station, Beltsville, Maryland). Each of these men contributed of their knowledge in the pursuit of this work.

Thanks must also be expressed to the many students who assisted in the collection and tabulation of field data. Mr. Luis Laje of Argentina and Mr. Dalmo Giacometti of Brazil are to be particularly remembered for their friendly cooperation.

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I. INTRODUCTION

Irrigation is an essential operation in some citrus areas. A California citrus specialist (19) has stated: "It has been truly said that irrigation is the most important operation under the control of the grower. The benefits of more frequent, light irrigations are so obvious for many groves that no one can afford to be complacent about trying to improve the situation." Apparently there is no question regarding the value of irrigation in that state.

Many citrus growers have too easily assumed that it was essential in Florida also. Many years of experience and research, however, have failed to settle definitely the value of this practice here.

Many discussions as to the feasibility of irrigation practices adapted to Florida citrus conditions have been held. In 1950 Dr. Werner Husmann, General Manager of Apshawa Groves, Inc., near Clermont in Lake County, in a conversation with the author, raised the question: "Does irrigation pay?" During the ensuing discussion a decision was made to investigate the matter under field operating conditions. Dr. Husmann offered favorable cooperation and the facilities of his organization.

The present research was undertaken to obtain additional data over a period of years which might permit a conclusive answer to the question of whether irrigation pays as a production practice in Florida.

II. REVIEW OF LITERATURE

Much has been written concerning irrigation in every agricultural area of the world. In Florida there has been a fairly constant stream of articles and papers with regard to the practice, but it is only within recent times that there have appeared attempts to really get to the bottom of the matter and to unearth information of more or less conclusive value. There have been many ramifications explored. Approaches have been made from laboratory study as well as from research in the field. Since the present studies were entirely from the standpoint of field conditions, it has been felt necessary to confine a discussion of the literature to those papers which refer to such conditions and bear upon the various phases of the problem currently explored.

Rainfall is the primary source of water for Florida citrus groves. Horticultural workers have often called attention to the fact that, although the annual rainfall is adequate for the needs of the crop, the distribution pattern results in periodic droughts. Wakelin (46) noted that in the winter of 1906-07 the usual fall drought had spread over the entire winter and merged with the expected spring drought, giving many sections of the state the driest period known in history. In the discussion which followed this paper L. B. Skinner recalled the drought of 1897-98 which killed whole regions of pine woods and oak woods in Pinellas County. Hoard (11) in 1908 noted that the scarcity of rainfall had been gradually getting worse for the past two or three seasons until at that time

irrigation (which was, of course, the only remedy) was regarded as almost essential. Stevens (43), however, concluded that irrigation is not an absolute necessity in Florida, as it is in some states, but that it can be made to serve a very good purpose if properly used.

Williams (47) was convinced of the need to supplement rainfall as an insurance against crop failures during dry periods. To substantiate his conclusions he compared the rainfall records of Florida with those of Milan, Italy, and Riverside, California. The strong feeling of similarity expressed by him between the problem in California and that in Florida was not universally accepted by his audience.

From a study of rainfall over a period of 22 years at Orlando, Stanley (40) concluded in 1914 that irrigation would have been beneficial in 17 years. Seven years had been very dry, "or one year in three had been dry enough to make the most skeptical wish that he had some way of watering his trees". He stated that the groves should have been watered 38 times to get the best results and that the loss from two years (1897-98 and 1906-07) alone would have paid for an efficient irrigation plant. By 1916 Stanley (42) had come to the conclusion that irrigation in Florida should be entirely supplemental to rainfall. He felt that it was required during approximately one-half the years and was not a necessity as in the West.

Staebner (38) also considered that, because of the rainfall distribution, irrigation would probably show a profit in about one-half of the years. In 1920 Kay (14) concurred with the remarks of Staebner that irrigation appeared to be needed during 10 of the

past 20 years.

By 1928 DeBusk (4) noted that grove irrigation in Florida was rapidly becoming one of the standard operations in citrus culture. He felt that the reason for such unusual activity and interest was obvious since, although there is an average of about 50 inches of rainfall per year, groves suffer during spring or fall in five out of seven years due to poor distribution. From a study of 35 years of rainfall records he found that the monthly rainfall was often insufficient for the needs of the trees. During this period he calculated that monthly rainfall was deficient in the different months during the following number of years out of the total 35:

January	10	May	15	September	2
February	16	June	none shown	October	10
March	24	July		November	23
April	25	August		December	10

DeBusk considered that rainfall was deficient if during the month there was evidence of shedding of bloom, young fruit, and even mature fruit during the fall and winter. Other, more intangible effects, such as influence on size and quality of fruit, were discussed also but he did not elaborate on these. He stated that the results of winter and early spring irrigation of the two previous years indicated that winter irrigation may be highly desirable under Florida conditions.

In 1933 DeBusk (5) gave the results of a 9-year study (1924-33) of the correlation of daily rainfall and soil moisture with citrus yields and size of fruit. Complete data were shown for eight of the nine years. Five of these years were rated with less than a 100

percent crop; two were dry during the fall period, while all of them showed drought periods during the spring months.

"We are in the midst of a severe drought so far as the citrus section is concerned", said O'Byrne (22), speaking before the meeting of the Florida State Horticultural Society in April of 1939. He felt that with the timber being cut, groves planted, swamps drained, and run-off of rainfall accelerated, droughts were becoming more frequent and severe. This seemed to him to be true at least in the Ridge section of the state. A severe drought had been suffered during May of 1938, and the following winter had been dry. Some tangerine trees had died as a result of the latter drought.

The fact of poor distribution of rainfall, with many periods of insufficiency, has been impressed upon everyone who has worked with citrus in Florida. The general thought which pervades the literature is that irrigation must be considered simply as needed to supplement inadequate rainfall during an average of one-half of the years, rather than as an obligate operation to be practiced every year.

Practically all of the water which enters the citrus tree finds access through the root system. Therefore, many have directed their attention to soil moisture studies.

Stanley (41, 42) discussed results obtained from soil moisture studies with samples taken every foot to a depth of six feet. His data, however, are meagre. In replying to a question, he (42) admitted that at the time (April, 1916) in some locations in the central part of the state, the ground was as dry as powder down to

six feet and yet the trees still remained alive; but he considered that a moist soil condition was necessary for maximum fruiting and best tree condition.

Reporting on Brevard County experiments in 1925, Kay (15) called attention to eight different soil types and 11 phases which prevail in the area and which all present problems of both deficient and excessive moisture. He found that, contrary to assumption, variations in moisture content at different locations under the tree were as great as those in any vertical section. In several instances tender, dry roots, half an inch or more in diameter, were found at depths from six to ten inches encased in a dry cylinder of soil about eight inches in diameter. In one instance there was only 1.64 percent moisture in the dry cylinder whereas the soil surrounding the cylinder contained from 6 to 7 percent of moisture. Kay noted that it was almost impossible to obtain saturation in the Norfolk soils. In these yellow soils he found a great range in capillary action, but the maximum (in a capillary tube) did not exceed 18 inches. Moist soil showed a greater range than did dry soil. The moisture content under the irrigation furrow in a Norfolk sand was found to be higher than that at the same depth lying 18 inches either to the right or to the left of the furrow. He noted that while the plant will grow in coarse sand at 2 percent moisture content, it will show wilt in a fine sandy loam with 10 percent moisture.

O'Byrne (22) observed that the damages in the tree from drought were greater in groves planted on poorly-drained soils, and that soils

underlain with clay were better able to hold moisture.

In a paper given in 1945 Jamison (13) discussed two types of non-wettability of soils. One type resulted simply from drying and the other appeared to occur as "dry bodies" beneath the citrus trees. This latter type was usually 10 to 50 times more difficult to wet than the same kind of soil from the tree middles.

Jamison presented four figures to show the way in which the soil wets after irrigation. He called attention to the questionable value of soil moisture determinations, taken either directly or with the use of instruments, on the deep sandy soils of the Ridge due to irregularities of wetting. He found that the soil was not equally wetted even after long periods of rainfall.

Furr (7) discussed the uneven drying of the soil resulting from the non-uniform distribution of roots. Trees with healthy root systems were found not likely to wilt, even under rather severe drought conditions, until well over half of the small absorbing roots were in soil at moisture contents in the wilting range. Apparently, contrary to some thought, desiccation of roots did not occur (except in the zone affected by surface evaporation) until all the root zone was dry. From studies on Orlando fine sand and Norfolk (Lakeland) fine sand he considered it apparent that during periods of drought the amounts of water absorbed by trees in deep light sand at depths below three or four feet may be very appreciable. He gave figures for the amount of available water in these soils by acre-inches.

With 80 percent efficiency, Furr considered 3.2 to 5.1 acre-inches (1554 to 2469 gallons per tree) needed to supply moisture deficiencies found in his soil samplings. He thought it would be most practical to wet to six or eight feet, and poor economy to wet to less than four feet. Since systematic soil samplings are not practicable for general grove irrigation management, he suggested frequent observations made with the use of a soil auger. If it can be avoided, trees should not be allowed to dry out to the point where they show definite wilting.

Koo (17) studied soil moisture fluctuations on Lakeland fine sand planted to Marsh grapefruit on Rough lemon rootstock at Lake Alfred. He found field capacity values ranging from 4.85 percent in the 0-6-inch zone to 3.38 percent in the 66-72-inch depth. Permanent wilting percentages varied from 0.80 percent in the surface 12 inches to 0.60 percent at depths of 48 to 72 inches. He noted that large numbers of samples are necessary to evaluate moisture contents of the soil properly, and that there was a close correlation between the distribution of feeder roots and moisture loss at the different depths in the soil. Moisture loss was obtained during intervals of no precipitation when the percentage of soil moisture was below field capacity, so that decreases in soil moisture represented losses through transpiration by the trees and evaporation from the ground surface.

Pot and field experiments conducted by Koo indicated that readily available moisture in the soil was not equally available

over the entire range from the field capacity to the permanent wilting percentage. There was shown a decrease in availability of this moisture after two-thirds of it had been removed. However, this reduction did not result in the appearance of wilting in the trees.

While some workers pursued studies of soil moisture, others have attempted to evaluate leaf moisture contents. Livingston and Brown (17) observed a diurnal fluctuation in foliar moisture content, and felt that such fluctuations might offer a means to foresee the need of increased soil moisture long before the occurrence of an actual wilt in the tree. Halma (8, 9), Oppenheimer and Mendel (23), and Compton (2) pursued this phase of research with citrus. Compton concluded that lack of available soil moisture appeared to be the most important factor in producing a high relative saturation deficit in leaves of the Washington navel orange under the conditions of high temperature and low humidity which prevail at Riverside, California, during the summer. Studies by Ziegler (50), however, indicated that under Florida conditions, apparently because of high relative humidity, leaf moisture content was not a reliable index for determining the need of supplemental water under field conditions.

Just as the depth of soil and its water-holding ability is important to an understanding of the problem, so too is the rooting system of the plant under consideration. All of the work with regard to root development of the Rough lemon rootstock on the light sandy soils of central Florida points to the deep-rooting nature of the system. Ford (6) found approximately 63 percent of the feeder roots

within 30 inches of the surface of the soil. However, roots have been found well below the 12-foot depth.

Another approach to the problem has been through the study of tree needs and estimates of water consumption. DeBusk (5) considered that the average bearing tree consumes approximately one inch of water every ten days, and that it was a generally recognized fact that moisture drawn from the soil was in direct proportion to root concentration. In his study of nine years of cropping he considered favorable rainfall from December through May as undoubtedly the principal factor during heavy crop years. Droughts during the spring period resulted in losses by droppage of fruit and in slow growth.

O'Byrne (22) noted that closely-planted groves suffered more seriously than did those planted at wider spacings. Differences were also apparent between varieties budded on various rootstocks. The Rough lemon rootstock showed less effect of drought than did others. Seedless grapefruit showed drought damages later than did tangerines or seedy grapefruit. O'Byrne felt that trees in good condition planted on soil in which the pH was maintained high showed the least damage. Practices which encouraged a widespread rooting system, allowing moisture withdrawals from large volumes of soil, appeared to have a favorable influence. Recovery of drought-damaged trees depended upon the ability to supply water before the trees had gone into a severe wilt and turned brown.

Jamison (13) considered that citrus trees probably withdraw little moisture from the soil five feet below the surface in the

deep sandy soils of Florida and estimated that, with an average of 5 percent available moisture, 1200 gallons of water would be available per tree on a 25 x 25 setting if evaporation from the soil surface could be prevented. He referred to Cowles' (3) work reporting that in February a 15-year-old grapefruit tree lost eleven gallons of water each day through its leaves. Considering the heavier foliage resulting from the correction of mineral deficiencies, Jamison estimated that a 20-year-old grapefruit tree in dry weather in May would probably require as much as 40 gallons of water per day. Therefore, if the soil were wetted to field capacity and the moisture conserved against surface evaporation, the application of one irrigation should provide adequate moisture for about one month in the older, closely-planted groves in the driest period during the year.

In a paper in 1951 Young (49) noted that even with sour orange rootstock, yields were substantially greater on the average for trees of equal age on the interior soils than on the coastal soils. By soil drainage improvement, assuming good distribution of roots, he showed that the amount of water available to the tree could be increased. In fact, he considered that trying to increase production through heavier fertilization or any other practice without first securing deeper rooting was, to a great extent, false economy.

In 1952 Koo (17) measured the evapo-transpiration rate of Marsh grapefruit on Rough lemon rootstock in the field at Lake Alfred. The actual measurements compared favorably in trend with calculations from the formulae of Thornthwaite (44) and of Blaney and Criddle (1),

but the total amount of water consumed by evapo-transpiration was found to be lower than that computed. When converted to acre-inches, an annual need for 38.47 inches was found.

Cropping responses, as determined by box yields, are considered excellent criteria for evaluating production practices. The indication that such responses from irrigation may be obtained under certain conditions in Florida was early recognized. Stanley (39) noted that in the long drought of 1906-07 the irrigated one-third of the Drennen Grove in Orlando bore more fruit than the other two-thirds and brought a much better price in the market. DeBusk's (5) 9-year study indicated that in several years supplemental water would probably have reduced droppage of fruit.

On the other hand, Reitz _et al_. (24) reported that during a period of three and one-half years irrigation treatments made no improvement in yield or fruit quality of either Valencia or Marsh on Sunniland or Parkwood soils as compared with similar plots receiving no irrigation treatment. In fact, the unirrigated Valencia plots yielded more fruit than did the irrigated ones. The soil was well-drained and there appeared to have been no water-damaged roots in recent years. The authors stated: "Under these conditions irrigation has not been a profitable operation. During unusual periods of prolonged drought it is undoubtedly necessary to irrigate to prevent fruit drop, but apparently an appreciable amount of water stress may be tolerated without loss of yield."

Sites _et al_. (36) obtained contradictory cropping results from

irrigation at the Citrus Experiment Station. However, at Haines City Valencia trees from irrigated plots produced from 0.5 to 1.1 boxes of fruit more than those from non-irrigated; for Marsh grapefruit the increase was from 1.5 to 2.5 boxes per tree. These workers questioned whether these differences in response might be due to the fact that November irrigation was given regularly at the Station whereas only in one year at Haines City. It was following this irrigation that the non-irrigated plots at Haines City outyielded those which received water.

Savage (33) studied yield data from irrigated and non-irrigated groves for eleven seasons (1941-53). His results showed that higher yields were obtained from irrigated groves in all age groups with the exception of that from 11 to 15 years.

In another study Savage (31) found that yield under irrigation was higher in groves which received low nitrogen fertilizer applications, but that such advantage disappeared when higher nitrogen levels were maintained. He (32) has also written as follows: "Little or no advantage is indicated for irrigated groves except possibly in the lowest nitrogen group. However, it is entirely likely that additional money spent for added fertilizer in this group would pay more returns than irrigation."

Young (48), in commenting on irrigation experiments in the East Coast area, stated that there was no question that irrigation was beneficial at times on the heavier soils in the low-lying areas, but that it was problematical whether it would pay on a great investment

under average weather conditions on the majority of these soils if proper control of ground water was secured. In 1951 Young (49) noted that improved drainage would afford increased production, paying dividends and allowing growers to prosper in a highly competitive field.

Yield, however, is not the sole criterion of value in the establishment of a commercial practice. The quality of the fruit must be taken into consideration. Sites (35) called attention to the fact that rainfall conditions can cause differences in quality as great as or greater than can be induced by any cultural or nutritional treatment. In a study of seven years, he found that two years (1940-41, 1942-43) which produced high solids in the fruit were characterized by lower rainfall during the months of June, July, August, and September, with a higher percentage of possible sunlight, and a lower number of cloudy days. He felt that much of the troubles with low solids in Hamlin and Parson Brown oranges during the past few seasons were undoubtedly due to weather conditions.

Sites et al. (36) reported upon a group of four irrigation experiments, two of short duration and two which extended over periods of years. The yield responses of the latter two have been reported above.

Marsh and Silver Cluster grapefruit were grown under two soil moisture regimes. One row received 500 gallons of water per tree per week as a supplement to rainfall from bloom to harvest; the other row depended upon rainfall as the sole source of water. After a

year's operation and from fruit tests made in September, October, and December, these men reported that with abundant soil moisture the fruit contained more juice, less soluble solids and titratable acid (on a percentage basis), and slightly higher ratio of solids to acids, but no consistent difference in Vitamin C content. They noted that, while the percentage of total soluble solids was lower in the irrigated fruit, the total weight on a "per fruit" basis was almost identical in the two plots and the data for acid were similar but more variable. Fruit from the irrigated block was one commercial size larger. The non-irrigated trees showed a wilt in June and produced a heavy June bloom. The early bloom fruit from the irrigated row did not grade out as well as did that from the unirrigated.

Sites and his coworkers studied Hamlin oranges for one year under five different soil moisture regimes. One plot was supplied with weekly increments of water to maintain field capacity. Each of the four remaining plots was given the same water conditions except for particular three-month periods of enforced dryness: January-March, April-June, July-September, and October-December. Continuous irrigation, while producing fruit of low solids and acids, increased the tendency to granulation or dryness of the fruit. All periods of enforced dryness (with the exception of the period October-December) showed generally increased percentages of soluble solids, acids, and Vitamin C contents in the fruit. Every three-month period of drought after fruit set reduced the size of the fruit, a reduction never entirely regained by subsequent irrigation.

During a period of four years, irrigation of orange and grapefruit varieties on Rough lemon rootstock produced fruit with lower percentages of soluble solids and titratable acids. Irrigation tended to reduce the Vitamin C content, but increases in solids/acid ratio and in volume of juice per fruit were noted. The irrigated plots produced larger-sized fruit. The results indicated that the keeping quality of Valencia oranges on the tree was impaired by the use of irrigation due to increase in granulation.

Again, at Haines City, Sites and his associates found that the percentages of soluble solids and acids were, in general, reduced under irrigation. They assumed these reductions to be due mainly to dilution because of the greater juice content of the fruit, and pointed out that such lowering is of importance particularly with varieties such as the Hamlin and Parson Brown oranges which frequently are delayed in marketing due to low solids and acids. The suggestion was made that irrigation applications later than June should not be used unless absolutely necessary to prevent pre-harvest fruit drop.

Voorhees _et al_. (45) reported that two applications of irrigation water to Valencia oranges at Ft. Pierce resulted in no increase in fruit size on Parkwood soil, while there was a very slight effect on Sunniland. Irrigation decreased the soluble solids in the Valencias, although the effect on ratio and Vitamin C content was slight. These results confirm those from the Lake Alfred studies of Sites _et al_. (36). The internal quality of Marsh grapefruit was little affected by

irrigation. Differences in yield were noted but were considered of little practical importance.

In the final analysis any commercial operation must be judged from the standpoint of its profitableness to the operator. Stanley (39), as noted above, reported increased yields and better market prices from irrigation during the 1906-07 drought. In 1919, Staebner (38) considered that irrigation would probably show a profit in about one-half of the years. Kimmel (16) reported that with 50 inches of rainfall a year, 50 percent from June to September and most of the remaining rainfall in a few heavy rains, the practice of irrigation was believed to pay dividends and was steadily on the increase. However, Young (48), as reported above, felt that it was doubtful whether the operation would pay on a great investment under average weather conditions on the majority of soils on the East Coast if proper control of ground water was secured. Savage (32) has been quoted above as convinced that additional nitrogen in the low-yielding groups of groves would pay more returns than would irrigation.

Irrigation equipment constitutes a considerable investment. Morton (21) reported on an irrigation project of a cooperative nature. Easy access to water was not available, yet no one of the growers concerned controlled sufficient acreage to warrant the expense of putting in a plant.

Savage (27) studied the investment in irrigation equipment from the records of 200 groves. On the 48 groves with grower-owned equipment, an average of $59.58 was invested per acre.

Furthermore, the operation of the practice increases costs rapidly. Howell (12) asked his audience: "Do you know that many growers who were dependent on portable irrigation during the past spring and summer (1950) have more money invested in the present crop for irrigation than for all other production costs combined?"

Savage (25, 26, 28, 29, 31, 33) has made many studies of the costs and returns from irrigation practices. Increased yields were often shown, but higher operating costs resulted in lowered net returns in many cases. In a mimeographed analysis (31) comparisons were made between returns above operating costs of irrigated and non-irrigated groves for the period 1940-53 according to the amount of nitrogen used per acre. Only when nitrogen was held at a low level did the returns show value for irrigation. As noted above (32), increased levels of nitrogen fertilization would most likely result in higher returns than would the practice of irrigation.

In another study, Savage (33) compared yields and returns of irrigated and non-irrigated groves by age groups. This study included eleven crop years. In commenting on the results, Savage (34) noted that with one exception (11-15 year group) the irrigated yield in each group exceeded that of the corresponding non-irrigated group. Returns above operating costs per acre were higher for the non-irrigated groves in the first four age groups, although in the four older groups irrigated groves netted most. He stated, "It is my conviction that at least part of the advantage shown for irrigation on trees 31 years of age and older is due to the crowding of the trees

on the land. Since these data reflect very little results from hedging it is entirely likely that hedged groves might show less advantage from irrigation."

Savage (30) has stated that the average cost of applying two inches of water was $15.25 per acre and that in order to make a profit there must be an increased yield which will net more than this amount. With this in mind he set up a table of the approximate number of boxes of fruit of various kinds necessary at the season's on-tree price to pay for each application. This paper afforded the grower a standard for comparison of the effectiveness of his irrigation program, but forced him, as Savage suggested, to designate two or more middles as controls that will never be irrigated.

Responses to irrigation varied widely from grove to grove in the economic studies of Savage. He found that in some groves irrigation has been profitable while in others it has not been and probably could not be. Results of irrigation may be influenced by age of trees, proportion of grapefruit to orange, variety of either species, rootstock employed, soil type, fertilizer and spray program, and spacing of trees, as well as by the irrigation method. In the present investigation all of the above factors are kept constant.

III. METHODS AND MATERIALS

A. The Experimental Grove

The grove chosen for the study of irrigation is under the management of Apshawa Groves, Inc., designated as Blocks 3 and 4, and located near Clermont in Lake County. The grapefruit portion of these blocks comprises approximately ten acres under similar cultural practices since being planted in 1927. The Marsh grapefruit (<u>Citrus paradisi</u> Macf.) trees on Rough lemon (<u>C</u>. <u>limon</u> (Linn.) Burmann) rootstock are set $28\frac{1}{2}$ x 30 feet, approximately fifty trees per acre.

The grove is at an elevation of approximately 25 feet from Lake Apshawa on a deep phase of Lakeland fine sand. With the exception of resets which have been required from time to time, a general uniformity was found to exist at the beginning of the experiments. Topographically the land is slightly rolling.

The fertilizer program through the year 1945 was a typical low-analysis one with low nitrogen and high potash such as was being used throughout the citrus areas of the state during that period. During the late thirties and early forties copper and other micronutrient elements were liberally applied along with the secondary element, magnesium. The program was gradually changed to the use of straight materials with higher levels of nitrogen and lower amounts of potash. From 1948 to date the majority of the applications have been of straight materials with an average N-P-K ratio of 1-0-1.

The pest control program has regularly effected the control of the

purple, six-spotted, and rust mites, the Florida red and purple scale insects, and the fungus disease, melanose. Micronutrient elements have been applied through the spray program, and so has arsenate of lead for early maturity.

No irrigation applications were given this grove prior to the beginning of the work. The elevation from the lake was too great for efficiency of operation until a permanent underground main was installed in 1950 which feeds into a system of portable irrigation lines by a series of risers. Irrigation during the experimental period was facilitated by means of 8-inch feeder lines and 6-inch perforated sprinkler lines of portable type.

Cultivation was quite similar to the general practices of Lake County, with a volunteer covercrop during the summer rainy season and clean cultivation during the winter. Pruning has been limited to the removal of dead wood. However, the blocks were "hedged" north and south during the first year (1951) of the research and east and west during April of 1954. The "hedging" practice, new to citrus culture, accomplishes the opening of middles seven to nine feet in width to allow better access to sunlight and grove equipment. Such a practice at least temporarily affects yields but any influences would be considered equal for all treatments. It should be noted, however, that the hedging of April, 1954, caused a setting of late (May) bloom fruit throughout the blocks irrespective of treatment. No firing was practiced since the grove is well elevated on the east side of Lake Apshawa.

Careful appraisal of the blocks prior to the setting up of the

experiment failed to reveal any location conditions which might militate unduly against any particular treatment. A general uniformity was found throughout the grove. No extraordinary nutrient deficiency, disease infection, or mite or insect infestation was encountered during the entire experimental period.

The yields from the season 1932-33 to the present are shown in Table 1. The average yields per tree for the years of the experiment include all treated and buffer trees. Therefore, they do not represent a simple average of treatment values but rather the actual picking records of the entire grove. In Table 1 is also shown the average rainfall - as determined from the records of the U. S. weather stations at Eustis, Orlando, and Bartow - which occurred during the January-June period preceding each crop year. In each case this rainfall is that which fell during the period when the particular crop was being set and beginning its growth in size.

B. The Experimental Treatments

Casual observations with respect to irrigation treatments and their results have been made by the author throughout many years of operating groves commercially. Two observations which appeared more prominent than others were noted. During a cold winter those blocks of trees which had been irrigated in the fall appeared to go through the freeze in better condition than did those suffering from lack of water. On the other hand, when considerable irrigation was applied to groves during the late fall period (November and December) of a particular year, immediately after installing a new irrigation system, the treated groves

TABLE 1

Average Rainfall[1] for January-June Period, and Cropping Record, in Boxes per Tree, of Marsh Grapefruit, Blocks 3 and 4, Apshawa Groves, Inc.

Year	Rainfall in Inches	Season	Yield in Boxes per Tree
1932	22.17	1932-33	0.20
1933	25.96	1933-34	0.58
1934	36.97	1934-35	3.14
1935	16.98	1935-36	0.89
1936	31.58	1936-37	5.06
1937	24.70	1937-38	1.34
1938	15.67	1938-39	7.63
1939	25.21	1939-40	5.41
1940	19.77	1940-41	5.00
1941	25.14	1941-42	6.03
1942	27.79	1942-43	1.93
1943	20.05	1943-44	8.86
1944	20.14	1944-45	7.58
1945	22.09	1945-46	13.64
1946	21.31	1946-47	6.60
1947	29.58	1947-48	8.50
1948	16.81	1948-49	6.35
1949	18.13	1949-50	11.20
1950	12.02	1950-51	11.05
1951	17.10	1951-52	14.35
1952	21.69	1952-53	9.65
1953	24.92	1953-54	15.70
1954	18.17	1954-55	11.82

[1] Average of three stations: Eustis, Orlando and Bartow, taken from records of U. S. Weather Bureau.

appeared to produce a smaller crop in the subsequent year than did those to which water could not be applied.

Writers have variously reported on the effects of winter and spring irrigation but unfortunately with little more definite evidence than is recounted above. As late as 1951, however, Sites et al. (36) suggested that the lower yield responses from irrigation at the Citrus Experiment Station at Lake Alfred, as compared with that at Haines City, might be due to November applications of water in the former case.

There is little doubt that spring irrigation needs are often more acute than are those of the fall period since:

1) The dry fall months have often reduced the water reserves in the soil;

2) The new growth appearing in the February-March period increases immensely the transpirational area of the tree;

3) Daily temperatures, particularly during the late March-April-May period, are often high;

4) Dry southeasterly winds often blow more or less constantly throughout the day during the March-April period; and

5) Bright, more or less cloudless, days decrease relative humidity, increase transpiration and evaporation, and bring little rain.

These considerations led to the determination to irrigate in the present experiment only during the spring months. During 1951, however, one September application of water was made. It is realized that such a limitation (to the spring period) will restrict the conclusions which might be drawn from the work. There is another factor, however, which

entered the picture, that of economical grove management. With costs averaging \$15.00 per acre per application, it was thought that the grower must use extreme care in avoiding excessive expense in this operation. Hendrickson and Veihmeyer (10), working with prunes, found that too little water may be injurious, but that unnecessary water was valueless. The restriction to the spring period would seem to maximize the value of the work and provide a stepping-stone to further experimentation in this field.

Amounts of water to apply at a particular time present a further problem. Growers are divided in their opinions. Some apply as little as one-half inch, while others supply as much as three or four inches per application. Furr (7) calculated the need of from 3.2 to 5.1 acre-inches per application to supply deficiencies found in Orlando and Norfolk (Lakeland) fine sands. Young (49) considered that the amount of water to apply per irrigation would depend upon drainage and soil structure. Sites et al. (36) used four rates in their work at Haines City: 0, 1½, 2½, and 3½ inches per application, but could show no consistent correlation between amount of water per application and yields.

Although the Rough lemon presents a deep tree-root system on Lakeland sand, Jamison (13) considered that little moisture was withdrawn from the soil five feet below the surface. Ford (6) found approximately 63 percent of the feeder roots in the 0-30-inch depth, and an additional 27 percent within the second 30 inches. With the assumption that the most effective rooting depth is approximately to four feet, it was felt by the author that this depth should be replenished to field

capacity at each irrigation period. Therefore, throughout the experiment approximately 2½ acre-inches were applied per irrigation, which, under ideal conditions, would bring the moisture level to field capacity to a depth of four feet. This amount is roughly equivalent to 67,500 gallons of water per acre, or 1,350 gallons per tree.

Applications were made of lake water carried through the underground main and distributed to the proper blocks by 8-inch, gasketed, lock-joint pipe; thence through 6-inch, perforated, gasketed lock-joint sprinkler lines.

One of the difficulties of irrigation experiments is that of setting up plots with proper buffer rows. Each treated plot consisted of from six to nine trees (Fig. 1) separated from other plots by two trees in a north-south direction and six trees in an east-west direction. Care was exerted by the operating crews to see that water was never introduced to any treatment plot except on the schedule maintained.

Assuming spring irrigation only, when should water be applied during such irrigation period? It appeared that three types of practices with regard to timing of applications were more or less general in Florida.

1) Some growers apply no supplemental water and, furthermore, are not equipped to irrigate their groves.

2) Many growers begin irrigation operations at the time of appearance of wilt in the trees (although under commercial practices now in vogue the trees are often allowed to suffer from the time such a

condition is observed until it is possible to get the equipment in operation).

3) A few growers, favorably situated with respect to water supply and distribution, maintain a schedule which more or less assures an ample soil moisture supply at all times.

It was felt that comparisons of these three types of irrigation practice should be made. A randomized block design was selected since by this means differences in topographical features throughout the grove might be more properly apportioned. With the use of a table of random numbers, and no prior knowledge of the grove conditions, treatments were assigned in each block. As shown in Figure 1, there were four blocks of three randomized treatments each.

The experimental treatments were as follows:

Treatment A - No irrigation applications.

Treatment B - Irrigation during the spring months at the first appearance of a temporary wilt in the tree. The objective was always to apply water before any permanent wilt appeared in the trees and therefore it cannot be stated with assurance that the trees would necessarily have gone into a permanent wilt. With the high relative humidity prevailing throughout Florida, the lag between temporary wilt and permanent wilt has been observed to be a period as short as three days and as long as two weeks or more. It should be stated that during the course of these researches the non-irrigated plots (Treatment A) were never observed to be in a permanent wilt; even a temporary wilt was of relatively short duration.

FIGURE 1

Design of the Experiment

BLOCK IV Treatment A (6 trees)	BLOCK II Treatment C (6 trees)
Treatment B (7 trees)	Treatment A (9 trees)
Treatment C (9 trees)	Treatment B (9 trees)
BLOCK III Treatment B (9 trees)	BLOCK I Treatment A (9 trees)
Treatment C (8 trees)	Treatment B (9 trees)
Treatment A (9 trees)	Treatment C (8 trees)

N

Treatment C - Irrigation during the spring months in such a manner as to maintain the soil moisture well above the permanent wilting point. At the outset this was to be accomplished, ideally, by regular soil sampling for moisture determinations. The outcome was not as ideal as the plan. (See discussion under "Studies of Moisture Availability".) However, it can be stated that at no time did the trees show any visible evidence of water needs of any description.

During the four-year period covered by these researches, no abnormal post-bloom shedding or June droppage occurred under any treatment. No particular late bloom occurred except during the last season (1954-55). As noted above, this late bloom (earlier than the usual June bloom) was found with all treatments and appeared to be associated with the east-west "hedging" (pruning) given the grove as a commercial operation in April of that year (1954).

The practical ineffectiveness of a short duration study was considered. To allow somewhat better comparisons, it was felt that four years should be given to the work. Even this, in retrospect, is insufficient for completeness. Nevertheless, it was conjectured that in a four-year period certain types of weather, particularly with respect to rainfall, would be encountered and that perhaps some values under such regimes might be adduced. The conditions with respect to rainfall are discussed under "Studies of Moisture Availability".

Soil moisture studies were considered as a regular part of the experiment at the outset, but, as noted later, work in this direction was reduced somewhat due to the inability to ascertain moisture levels properly.

The dates of irrigation by treatment are shown in the following schedule.

Fruit Season	Treatment		
	A	B	C
1951-52	None	May 30, 1951	March 12, 1951 May 8, 1951 May 30, 1951 Sept. 11, 1951
1952-53	None	June 5, 1952	May 3, 1952 June 5, 1952
1953-54	None	None	March 17, 1953 May 12, 1953
1954-55	None	May 24, 1954	April 26, 1954 May 24, 1954 June 21, 1954

C. The Methods of Data Collection and Analysis

Studies were made of rainfall records, soil moisture, and leaf moisture during the course of this work. The methods used in these studies are discussed later together with the results obtained.

The primary objective, however, was an attempt to arrive at an answer to that perennial question: "Does irrigation of citrus under either of the above-described treatments produce a profit to the Florida grower?" The answer to this question would seem to be undoubtedly and easily ascertained by cost and yield records. Therefore, at picking time each year the records of the various plots were totalled in standard field boxes which hold approximately 2.2 bushels. The operation was carefully supervised in each case to see that proper credits were made and that the boxes were uniformly filled. All figures were then computed for production in boxes per individual tree. With approximately

50 trees per acre, the production per acre can be calculated by simple multiplication. In all computations of costs of production it was considered that the base cost (for fertilization, spray practices, etc.) would be similar for the various plots. The average production cost per box of grapefruit in Lake County is approximately \$0.55. The cost of irrigation is considered to be \$15.00 per acre per application, which approximates the state average for this operation.

Certain other data were felt to be worthwhile, however. Fruit size studies were made since increases in yield might be due to increase in size of the individual fruits, or to increase in the number of fruit per tree. Each year measurements of the cross-sectional diameter of the fruit were made with the use of a standard fruit caliper manufactured by A. J. Jacocks, Winter Haven, Florida. These measurements were recorded in inches and tenths. During the season 1951-52 large numbers of fruit were used for comparisons, from all sides of the trees. During the following three seasons, however, as justified by sample size data, smaller numbers of fruit were included in the size studies by the use of fruit singly held at the south-east corner, or on the east side, of the trees.

Maturity studies were also made, since yield alone does not necessarily give the true picture of fruit value. Each maturity test was conducted with the use of five fruits of a particular size, one from a particular location on each of five trees for each plot. This is the standard sample used in running maturity tests under state law.

Juice was extracted with the use of a motor-driven reamer as

allowed by state law. The juice of five fruits was measured in milliliters and such measurements were divided by five to obtain the average per fruit. The motor-driven reamer extracts the juice well, but it must be noted that there are differences in the amounts of juice obtained due to differences among operators. In order to reduce the error by standardizing this process, each series of tests was conducted by the same operator.

Total soluble solids include sugars, acids, ascorbic acid (Vitamin C) as well as other organic and inorganic compounds dissolved in the juice. The determination of solids on a percentage basis was obtained by the use of the Brix hydrometer standardized at 17.5° C., with readings corrected for temperature.

The percentage of anhydrous citric acid was obtained by titration against the standard alkali (sodium hydroxide) provided by law, with the use of phenolphthalein as the indicator.

The maturity ratio, an indication of consumer acceptability, is simply the quotient of the percentage of soluble solids divided by the percentage of anhydrous citric acid; it is termed the solids/acid ratio.

The pounds of total soluble solids and citric acid per box of fruit were calculated by the use of the following equations:

$$\text{ml. juice/fruit} \times \text{size} \div 3785.3 = \text{gallons juice/box} \tag{1}$$

$$\text{gallons juice/box} \times \text{weight/gallon} \times \text{Brix reading} = \text{pounds total soluble solids/box} \tag{2}$$

gallons juice/box x weight/gallon x percentage of anhydrous

citric acid = pounds of anhydrous citric acid/box (3)

In the above equations, the size refers to the number of fruits per standard packed box of 1-3/5 bushels. Standard sizes for grapefruit are 36, 46, 54, 64, 70, 80, 96, 112, and 126.

The factor 3785.3 represents the number of milliliters per gallon.

The weights per gallon (Table 2) are those used in the commercial processing plants of the state.

All statistical analyses were made on the basis of variances derived from the randomized block design in making comparisons between treatments. The F. values given are based on two degrees of freedom for comparisons between treatments and six degrees of freedom for error (the interaction between blocks and treatments). An F value of 5.14 is required at a 95 percent confidence level and all such comparisons are considered significant and marked with a single asterisk. An F value of 10.92 is required at a 99 percent confidence level; all such comparisons are considered highly significant and marked with a double asterisk. Such analyses, together with others used herein, were those presented by Snedecor (37).

TABLE 2

Relationship between Brix Reading and
Weight per Gallon of Citrus Juices

°Brix	Weight in pounds/gallon	°Brix	Weight in pounds/gallon
7.5	8.555	8.8	8.594
7.6	8.558	8.9	8.597
7.7	8.561	9.0	8.600
7.8	8.564	9.1	8.603
7.9	8.567	9.2	8.606
8.0	8.570	9.3	8.609
8.1	8.573	9.4	8.612
8.2	8.576	9.5	8.615
8.3	8.579	9.6	8.618
8.4	8.582	9.7	8.621
8.5	8.585	9.8	8.624
8.6	8.588	9.9	8.627
8.7	8.591	10.0	8.630

IV. RESULTS AND DISCUSSIONS

A. Studies of Moisture Availability

1. Rainfall Records

The work of DeBusk(5) held certain indications that the amount of autumn rainfall might influence the crop of the next season. Even though no irrigation was planned for the fall period, it seems highly desirable to consider the rainfall year to begin October 1 and terminate September 30. In such an assumption a serious error in calculation could occur if a very light rainy season is followed by an early fall drought which causes excessive mature fruit droppage. Except for this contingency, however, the assumption seems realistic.

The crop year of 1951-52 (the first of the current experiment) would be influenced highly by the rainfall year of 1950-51. In order to obtain a general idea of rainfall conditions, the records of four stations within a 50-mile radius of the planting for the four rainfall years (1950-51, 1951-52, 1952-53, and 1953-54) are shown in Tables 3, 4, 5, and 6. These records, together with their averages, might in a general way type the conditions as to rainfall.

Rainfall records, with the use of a standard rain gauge, were taken at the grove headquarters, about one-half mile from the site of the experiments, beginning in January of 1953. These are recorded in Tables 5 and 6.

The amounts of precipitation occurring at two stations in rather close proximity to each other often vary more widely than does the rainfall between more distant points. Note the differences in monthly

TABLE 3

Precipitation at Various Stations for Period, October, 1950 through September, 1951[a] (expressed in inches)

Month	Eustis	Orlando Airport	Orlando Water Plant	Bartow	Average
October	11.85	14.51	11.12	7.26	11.18
November	0.06	0.09	0.04	0.06	0.06
December	4.31	4.30	4.38	4.13	4.28
January	0.50	0.52	0.59	0.33	0.48
February	2.53	2.28	2.54	2.13	2.37
March	1.35	0.96	1.01	2.63	1.49
April	1.49	5.99	5.22	8.40	5.28
May	0.40[b]	1.40	1.33	0.45	0.90
June		5.08	5.51	8.21	6.27
July	6.85	14.51	15.04	12.72	12.28
August	3.32	7.84	9.21	8.10	7.12
September	8.07	9.34	8.72	5.82	7.99
TOTAL	[b]	66.82	64.71	60.24	59.70

[a]From records of the U. S. Weather Bureau.
[b]Incomplete record.

TABLE 4

Precipitation at Various Stations for Period, October, 1951 through September, 1952[a] (expressed in inches)

Month	Eustis	Orlando Airport	Orlando Water Plant	Bartow	Average
October	0.80	3.08	3.40	1.05	2.08
November	3.75	4.86	4.27	5.80	4.67
December	2.45	2.08	2.14	1.18	1.96
January	0.53	0.70	0.93	0.69	0.71
February	6.51	5.47	5.89	5.26	5.78
March	5.81	6.67	6.08	5.74	6.08
April	0.91	2.88	1.82	0.46	1.52
May	4.18	2.45	2.23	6.98	3.96
June	3.80	2.32	2.72	3.70	3.14
July	6.92	4.43	5.56	8.28	6.30
August	2.43	6.51	9.62	7.58	6.54
September	5.75	4.94	6.74	2.98	5.10
TOTAL	43.84	46.39	51.40	49.70	47.84

[a]From records of the U. S. Weather Bureau.

TABLE 5

Precipitation at Various Stations for Period, October, 1952 through September, 1953[a] (expressed in inches)

Month	Eustis	Orlando Airport	Orlando Water Plant	Bartow	Average	Apshawa
October	5.96	3.69	3.71	8.98	5.58	
November	0.55	0.74	0.69	2.45	1.11	
December	1.20	0.65	0.34	1.62	0.95	
January	2.95	2.86	3.21	2.89	2.98	2.55
February	4.85	2.89	4.50	2.68	3.73	3.00
March	6.48	3.03	3.38	1.45	3.58	6.05
April	5.43	6.18	5.30	4.39	5.32	6.12
May	1.47	1.87	1.20	0.87	1.35	1.91
June	4.45	6.28	9.20	13.74	8.42	5.81
July	6.55	6.85	5.57	8.31	6.82	11.17
August	9.35	15.19	17.02	7.73	12.32	9.47
September	8.20	8.84	11.58	10.58	9.80	6.52
TOTAL	57.44	59.07	65.70	65.69	61.96	

[a]Apshawa records taken from grove records; all others from U. S. Weather Bureau.

TABLE 6

Precipitation at Various Stations for Period, October, 1953 through September, 1954[a] (expressed in inches)

Month	Eustis	Orlando Airport	Orlando Water Plant	Bartow	Average	Apshawa
October	2.56	3.50	3.79	3.22	3.27	2.00
November	2.32	4.78	5.43	5.97	4.62	3.05
December	4.90	3.58	3.75	4.95	4.30	7.38
January	0.98	0.45	0.64	2.53	1.15	0.66
February	1.54	1.16	1.16	2.34	1.55	0.94
March	1.28	0.99	1.12	1.34	1.18	2.23
April	2.69	4.44	6.96	6.12	5.05	1.79
May	2.92	3.55	3.49	7.82	4.44	2.04
June	3.30	5.81	4.42	5.24	4.69	6.22
July	4.93	13.64	11.00	8.85	9.60	7.35
August	6.47	4.39	7.47	6.07	6.10	6.19
September	2.63	3.99	4.43	2.88	3.48	6.35
TOTAL	36.52	50.28	53.66	57.33	49.43	45.20

[a]Apshawa records taken from grove records; all others from U. S. Weather Bureau.

rainfalls which occurred at the Orlando Airport and the Orlando Water Plant, which are only four miles apart.

Statistical studies of rainfall records from stations within a 50-mile radius of the experimental site were undertaken. Preliminary studies indicated that there is a highly significant difference in rainfall from month to month, but that the monthly records from the different stations rarely show significant differences.

The monthly rainfall records of six locations (Orlando, Bartow, Eustis, Sanford, Deland, and Ocala) for seven years (1918 through 1924) (20) showed a statistical value between stations for the months of January and March only. These are months of normally low rainfall. Differences of statistical value for years by months were shown in every month with the exception of August. The F values are given in Table 7. Even in this short interval is shown that which so many growers and researchers have observed: although an average rainfall may be calculated for each month, the variations entering into such averages are wide. So wide, indeed, are these variations from year to year that not even in the lifetime of a person could he have properly sampled rainfall for an individual station.

From the results of these studies it was assumed that, although the daily rainfall might vary between locations, the monthly rainfall will tend to level off such differences.

2. Soil Moisture

Practically all of the water used by the citrus tree is taken up through the root system from the soil. Therefore, it appears to be a

TABLE 7

F Values from Analyses of Variance of Rainfall Recorded at U. S. Weather Stations at Orlando, Bartow, Eustis, Sanford, Deland, and Ocala[1]

Month	F Values	
	For years	For locations
January	20.336**	2.969*
February	25.546**	0.708
March	90.990**	2.697*
April	20.760**	0.682
May	15.539**	1.319
June	2.856*	0.457
July	6.207**	0.902
August	2.359	0.688
September	10.380**	1.520
October	8.080**	1.352
November	22.586**	1.535
December	9.506**	1.022
ENTIRE YEAR	9.930**	2.816*

For years: F_{05} 6,30 - 2.42; F_{01} 6,30 - 3.47

For locations: F_{05} 5,30 - 2.53; F_{01} 5,30 - 3.70

[1]Based on records for 1918 through 1924 taken from Florida Agric. Expt. Bul. 200 (20).

reasonable assumption that periodic samplings of the soil for moisture determinations might give a proper clue to the need for replenishing such a soil-water reservoir.

At the beginning of the work it was felt that periodic samplings during the spring period should be made in the various plots. The author (50) had previously studied soil moisture conditions in Arredondo fine sand planted to citrus on the campus of the University. Four borings to a depth of one foot were taken on each sampling date. Moisture determinations were made from each boring by the oven-dry method and the average percent by weight was then calculated. When the weekly rainfall was graphed against the weekly soil-moisture content, there appeared to be a satisfactory correlation.

With the expectation that a similar system might obtain on Lakeland fine sand, four borings were taken from the 0-12-inch depth from the middles of each plot at intervals during the spring of 1951. Each set of borings was mixed by hand and run as a composite sample. In Table 8 are given the results of such determinations for the period from March 31 through June 23 as averages of the four plots under each treatment. That the moisture content, as determined, was influenced by irrigation is indicated. However, no statistical values could be placed on the differences because of the variations in the moisture contents of individual composites. An analysis of variance indicated that approximately 50 such samples would be required to detect a mean within five percent of the true mean at a 95 percent confidence level, and approximately 90 at a confidence level of 99 percent.

TABLE 8

Soil Moisture Contents in the 0-12-inch Depth
under Different Treatments in 1951
(as percentage of dry weight)

Date	Treatment[1] A	B	C
March 31	2.87	2.26	2.52
April 14	2.09	2.34	2.27
April 28	1.86	2.04	1.99
May 12	2.11	1.88	2.37
May 26	1.06	0.94	1.10
June 9	1.40	2.12	2.45
June 23	2.20	2.46	2.50

[1] Irrigation treatments during this period were as follows: Treatment A, none; Treatment B, May 30; and Treatment C, March 12, May 8, and May 30.

During the spring of 1952, although regular samplings were not made, numerous borings were taken to depths of four feet. From each such boring the soil was separated according to the following depths: 0-12, 12-24, 24-36, and 36-48 inches. All borings were taken from Block I and for each sampling date determinations were made of composites of three borings for each depth. The data from these determinations for the period January 19 through July 12 are given in Table 9. In all, 26 composites for each depth were run. No attempt was made to relate the moisture contents found with the needs for irrigation, even though there might be seen some influence of the irrigation treatments. The number of borings was not sufficient to obtain a satisfactory mean, nor would time permit the taking of sufficient samples for this purpose.

Such borings were made because many workers have considered the soil under a tree as a water reservoir and have felt that any proper

TABLE 9

Soil Moisture Contents from Block I in 1952
(Each determination represents a composite of three borings)

Date	Percentage of Soil Moisture			
	0-12"	12-24"	24-36"	36-48"
		Treatment A[1]		
January 19	1.65	2.73	2.52	2.75
February 2	2.55	2.66	2.50	2.90
February 16	3.92	5.30	5.69	3.43
March 1	3.39	4.34	4.28	4.52
March 29	3.16	3.28	4.24	3.38
May 10	1.23	2.70	2.22	1.62
May 24	1.74	1.44	1.15	0.61
June 28	1.82	2.82	0.84	0.58
		Treatment B		
February 16	4.48	4.43	3.46	2.27
March 1	3.62	3.88	4.35	4.57
March 15	6.25	4.01	3.43	3.04
March 29	3.02	3.90	3.60	4.05
May 10	1.38	2.59	2.07	1.75
May 24	1.96	2.26	1.23	0.75
June 28	2.29	2.77	1.89	1.70
		Treatment C		
February 2	2.84	2.86	2.43	2.50
February 16	5.82	5.30	5.05	3.98
March 1	2.84	3.32	3.80	3.90
March 15	6.80	6.27	5.07	2.78
March 29	3.06	3.56	3.90	4.02
May 10	2.32	2.84	2.89	2.77
May 24	1.85	2.00	1.80	1.68
June 28	2.41	2.20	1.97	2.20
July 12 - 1st sampling	3.71	2.22	4.18	4.09
2nd sampling	2.81	3.42	3.39	3.53
3rd sampling	2.95	2.88	3.86	4.16

[1] Irrigation treatments during this period were as follows: Treatment A, none; Treatment B, June 5; and Treatment C, May 3, and June 5.

determination of soil moisture must contemplate the utilization of the entire soil profile occupied by the roots of the plant. Ford (6) has found, as previously noted, considerable rooting of Rough lemon in the 5-9-foot depth of the soil, and has even found roots at a depth of 17 feet in cases where drainage conditions of the soil would permit. Koo (17), as noted above, recorded a certain relationship existing between soil moisture and amount of roots at the various depths in the soil.

The author has felt that it would not be necessary to probe the entire soil depth to gain a knowledge of the moisture conditions present, provided sufficient samples were taken from a particular profile. The number of samples required to calculate the total water resources would definitely be prohibitive. Therefore, from the data shown in Table 9, regression correlations of the moisture content at depths of 12-24 inches, 24-36 inches, and 36-48 inches on that at depth of 0-12 inches were run. The following results were obtained:

Depth	Regression equation	r	d.f.
12-24	$1.310 + 0.6374X$	.7990**	24
24-36	$1.145 + 0.6513X$	.7221**	24
36-48	$1.630 + 0.3899X$	.4651*	24

There was found to be a highly significant correlation between the moisture found at the 0-12-inch depth and that at the depths of 12-24 and 24-36 inches, and a significant correlation between the 0-12-inch depth and that at the 36-48-inch depth. The regression equations express these relationships. Although the data from which the correlations were run were obtained from various treatments, the depths were from the same borings. These data would appear to strengthen the conclusion that

the moisture contents of the different sections of the soil profile, to the depths probed, are related and that borings to a particular depth might give valuable approximations of the total water reservoir condition. It is further felt that these relationships are due to the rooting patterns of the Rough lemon root-stock.

In 1953 Koo (17) gave, in his Table 31, moisture contents found at the following depths: 0-6, 6-12, 12-18, 18-24, 30-36, 42-48, 54-60, and 66-72 inches. From this table 42 sampling dates were selected at random from the periods: October 1 through December 27, 1951; February 4 through March 31, 1952; and June 5 through July 30, 1952. Regression correlations of the moisture content at the various depths on that at depth 6-12 inches were run, with the following results.

Depth	Regression equation	r	d.f.
0- 6	$-0.909 + 1.2593X$	.9253**	40
12-18	$0.285 + 0.8705X$	.9686**	40
18-24	$0.106 + 0.8760X$	.9134**	40
30-36	$-0.003 + 0.8361X$	.8097**	40
42-48	$0.435 + 0.6998X$	.6731**	40
54-60	$1.288 + 0.4796X$	.4895**	40
66-72	$1.506 + 0.4566X$	.4566**	40

Here was found a high degree of correlation of soil moisture contents for all depths with that at the 6-12-inch depth, and, therefore, of one depth with another.

In order to test the equations from Koo's data, the field capacity figures from such equations are compared with those which this worker found in his studies. His figure for the moisture content at the depth of 6-12 inches was used in testing the equations. Table 10 shows these comparisons.

TABLE 10

Moisture Contents of Lakeland Fine Sand at the Field Capacity as Found by Koo and Calculated from Regression Equations

Depth in inches	Found (%)	Calculated (%)
0- 6	4.85	5.05
6-12	4.73	----
12-18	4.33	4.40
18-24	4.28	4.25
30-36	4.08	3.95
42-48	3.92	3.74
54-60	3.58	3.56
66-72	3.38	3.67

Further tests of the equations were made with figures given by Koo, in his Tables 33 and 34, as averages of 36 borings made on February 12, 1953. The average figure given by Koo for the 6-12-inch level was used in testing the equations. Results are shown in Table 11.

TABLE 11

Moisture Contents of Lakeland Fine Sand, on February 12, 1953, as Found by Koo and Calculated from Regression Equations

Depth in inches	Found (%)	Calculated (%)
0- 6	4.08	4.65
6-12	4.42	----
12-18	4.07	4.13
18-24	4.02	3.98
30-36	3.58	3.69
42-48	3.60	3.53
54-60	3.46	3.41
66-72	3.50	3.52

In each of the two tests of the regression equations, satisfactory results were obtained. The conclusion appears tenable that any estimate of soil moisture conditions can most easily be implemented by sampling the 6-12-inch depth and directing the maximum attention toward large

sample size at this depth. Differences in soil textures and structures and rooting habits of the trees must be taken into consideration in setting up the regression equations.

A further test of the equations was made with figures given by Koo (17, p. 38) showing the soil moisture contents found at permanent wilting point at the different depths on Lakeland fine sand, and being an average of ten replicated greenhouse determinations for each depth. These comparisons are shown in Table 12.

TABLE 12

Moisture Contents of Lakeland Fine Sand at the Permanent Wilting Percentage as Found by Koo and Calculated from Regression Equations

Depth in inches	Found (%)	Calculated (%)
0- 6	0.82	0.10
6-12	0.80	----
12-48	0.70	0.86
48-72	0.60	1.77

There is shown to be no agreement between the two sets of figures. However, when one considers that those obtained by Koo were taken from soil placed in containers under greenhouse conditions, the differences noted can be justified. Under actual field conditions the 0-6-inch depth is acted upon by surface evaporation. The moisture content would be reduced below the permanent wilting percentage, even though not affected by withdrawals by the plant-root system. The fair agreement in the depth of maximum rooting (12-48 inches) is reasonable. The agreement at the 48-72-inch depth again is not good. Here the lesser amount of rooting under field conditions influences the moisture percentage at the point of permanent wilt and it is entirely feasible that the

soil at this depth may never reach the low moisture contents found in the laboratory. Kay (15) and Jamison (13) noted the differences found in soil moisture due to root permeation, and Koo (17) found that moisture loss at the different depths held some relationship to amount of rooting at these depths. It is felt, therefore, that the percentage of moisture at the permanent wilting point calculated by the equations might more closely resemble the condition existing under actual field situations than that found by laboratory methods. It would further appear that permanent wilting percentages found in the laboratory afford little information of direct value to the field worker.

Soil sampling was continued during the spring of 1953 with borings taken from the 6-12-inch depth. This depth was used since it was considered more representative of soil in which surface evaporation was minimized and plant withdrawals maximized. Each figure, as presented in Table 13, represents the average of four plots under the particular treatment, which in turn were the composites of six borings per plot. There was again found to be some relationship of moisture content to treatment. Based upon the figures for the four plots under Treatment A (no irrigation) it was found that the following numbers of samples (each a composite of six borings) would be required to estimate a mean within five percent of the true mean at the two confidence levels.

Sample Size Based on Analysis of Variance

Confidence Level	Samples required to obtain a mean within the given percentage of the true mean:			
	5%	10%	15%	20%
95%	25	6	3	2
99%	45	11	5	5

TABLE 13

Soil Moisture Contents in the 6-12-inch Depth under Different Treatments in 1953 (as percentage of dry weight)

Date	Treatment[1]		
	A	B	C
January 3	1.78	1.96	1.97
January 29	2.88	2.78	2.88
February 14	2.66	3.05	2.93
February 28	2.02	2.44	2.23
March 14	3.20	3.00	3.23
March 28	3.46	3.16	3.23
April 11	3.04	3.30	3.46
April 25	2.80	2.78	2.93
May 23	3.26	3.32	4.11
June 8	3.75	3.85	4.32
June 18	3.07	2.98	3.60

[1] Irrigation treatments during this period were as follows: Treatments A and B, none: and Treatment C, March 17, and May 12.

Koo (17) found that for a confidence level of 95% at the 6-12-inch depth, 46 single borings would be required to obtain a mean within five percent of the true mean. Comparing this figure with that obtained by the author, it would appear that compositing the six borings per individual determination reduced the number of such determinations from 46 to 25, but that 150 (25 x 6) individual borings would be required against only 46 for Koo's method.

Regular soil moisture determinations were made from samples taken from the southeast corner (drip) of five particular trees in each treatment of Block I during the spring of 1954. Each boring was made from the 6-12-inch depth and run as a separate determination. In Table 14 are given the averages for the different treatments.

These soil moisture determinations showed, again, the influence of

TABLE 14

Soil Moisture Contents in the 6-12-inch Depth under Different Treatments in 1954 (as percentage of dry weight)

Date		Treatment[1]	
	A	B	C
February 13	2.68	2.91	2.73
March 13	4.03	3.33	3.44
March 27	3.55	2.94	2.93
April 10	3.84	3.14	3.46
April 24	4.56	2.69	3.05
May 15	3.99	3.30	3.74
May 29	2.73	3.35	4.34
June 26	3.73	3.97	4.60

[1] Irrigation treatments during this period were as follows: Treatment A, none; Treatment B, May 24; and Treatment C, April 26, May 24, and June 21.

irrigation treatments. However, at no time during the experiments was complete confidence placed in the soil samplings because of the inconsistent results due to insufficient sample size. Further samplings were precluded because of the time element involved in the work.

In conclusion, it would seem apparent that, at best, soil sampling for moisture determinations will be of value only to ascertain trends; no practical use can be made of it under conditions of actual field operations in citrus grove management because of the very large number of borings required.

3. Leaf Moisture

The author (50) studied moisture saturation of leaf and twig of certain varieties of citrus as an indication of soil moisture conditions. In conclusion, it was stated: "The twig and leaf moisture content of Florida citrus is not a reliable index to soil moisture content and for

commercial growers is, therefore, not a satisfactory means of determining whether supplemental moisture is needed to maintain the proper moisture balances in the tree." This conclusion appeared to be justifiable due to the high effect of relative humidity upon moisture loss from the leaf under any soil moisture regime.

Nevertheless, it was felt that the above conclusion should be tested under the conditions at the Apshawa Groves. Accordingly, in the spring and summer of 1954 collections of fully-grown leaves of the spring flush were made at regular intervals from the treatment plots of Block I. On each collection date three samples were taken from individual trees under each treatment. A sample consisted of 20 leaves from a particular tree, five from each cardinal point of the compass, taken between 11:30 a.m. and 12:30 p.m., and immediately placed in rubber-gasketed jars. The fresh weight was obtained, after which the leaves were dried in an oven at 105° C. for 24 hours. The loss is recorded as the percent of fresh weight. In Table 15 are given the results of these determinations as averages of the three collections from each treatment.

In Table 15 is also given the analysis of variance for the dates May 15 through July 24, during which period the effects of the treatments might be noted. It will be seen that the variations between individual trees were statistically highly significant and that the greater portion of such variation was contributed by differences between treatments. Unfortunately, however, the differences in moisture under the single irrigation treatment vs. no irrigation were not of significance. The great differences occurred in comparisons of Treatments A

TABLE 15

Moisture Contents of Spring-Flush Leaves in 1954
(as percentage of fresh weight)

Date	Treatment[1]		
	A	B	C
April 10	72.2	72.2	72.7
April 24	67.7	67.7	67.9
May 15	65.2	65.3	66.0
June 12	63.9	64.0	65.3
June 26	63.2	63.6	67.1
July 10	64.1	64.5	66.7
July 24	63.6	63.3	65.9

[1] Irrigation treatments during this period were as follows: Treatment A, none; Treatment B, May 24; and Treatment C, April 26, May 24, and June 21.

Analysis of Variance
For dates May 15 through July 24

Source	d.f.	ss.	ms.	F
Total	44	96.67		
Dates	4	9.09	2.2725	2.442
Trees	8	57.80	7.2250	7.764**
Plots	2	45.36	22.68	10.941**
Trees within plot	6	12.44	2.073	
Error (dates x trees)		29.78	0.9306	

F_{05} 4, 32 - 2.67; F_{01} 4, 32 - 3.97 - for dates

F_{05} 8, 32 - 2.25; F_{01} 8, 32 - 3.12 - for trees

F_{05} 2, 6 - 5.14; F_{01} 2, 6 -10.92 - for plots

and B with Treatment C. It appears that the greater soil moisture occurring with the repeated irrigations of treatment C increased on all collection dates the percentage of moisture in the leaves.

There is an indication here that leaf moisture may be increased by increased soil moisture contents. From the practical standpoint, however, further work must be undertaken to determine whether, and in what way, these differences may be useful.

B. Studies of the Effect of Irrigation on Fruit Yield and Quality

1. Yield

During each of the four years the treatment plots were picked and the yields calculated in boxes per tree (Table 16).

During each year under study there was an increase in yield in plots which received supplemental water. The data for the seasons 1951-52 failed to show differences with 95 percent confidence. No statistical significance can be placed on the data for the seasons 1952-53 and 1953-54. However, the results for 1954-55 showed highly significant differences between treatments and when the data for the entire four-year period were analyzed significant differences were again shown. These plot averages are also shown in Table 16.

Due to the alternate-bearing habit of grapefruit, yearly fluctuations in yields are to be expected. The significance shown for the cumulative yields over the four-year period would be expected due to the consistent increase in yield of the irrigation treatments over the non-irrigated plots. These cumulative figures indicate that there are

highly significant differences in yields for irrigation vs non-irrigation, and significant differences for irrigation at temporary wilt vs. irrigation applied to maintain soil moisture level.

The citrus grower, however, is interested in the economics of the operation. The average cost of an application of two and one-half acre-inches of water is approximately $15.00 per acre. The data presented in Table 17 substantiate the theory that irrigation is an operation which may prove economically sound with good management.

TABLE 16

Yields of Marsh Grapefruit per Tree, for Season, Block, and Treatment (expressed in field boxes of 2.2 bushels)

Season	Block	Treatment A	Treatment B	Treatment C	F value	LSD 05	LSD 85
1951-52	I	14.8	15.4	17.5			
	II	12.1	17.4	19.3			
	III	13.8	15.3	15.5			
	IV	14.0	15.4	15.0			
	Average	13.68	15.88	16.82	4.561		
1952-53	I	11.1	10.8	11.5			
	II	7.3	11.3	14.2			
	III	8.1	9.2	9.1			
	IV	9.4	10.6	10.6			
	Average	8.98	10.48	11.35	2.406		
1953-54	I	17.3	16.6	19.7			
	II	15.5	19.4	20.3			
	III	17.4	16.4	17.4			
	IV	16.7	19.5	16.0			
	Average	16.72	17.98	18.36	0.873		
1954-55	I	11.2	11.9	12.7			
	II	9.4	12.0	14.5			
	III	10.2	12.9	13.8			
	IV	11.5	13.4	14.6			
	Average	10.58	12.55	13.90	18.276**	0.142	0.222
Average for all plots and years		12.49	14.22	15.11	45.424**	0.718	1.126

TABLE 17

Cumulative Figures of Costs and Production for the Four Years of the Study

	Treatment		
	A	B	C
Boxes per tree, for four years	49.96	56.89	60.43
Boxes per acre, for four years	2498.00	2844.50	3021.50
Increase in boxes per acre over that of Treatment A		346.50	522.50
Number of irrigation applications	0	3	11
Cost per acre for irrigation		\$45.00	\$165.00
Cost per box of additional boxes		\$ 0.13	\$ 0.316

If, as considered under "The Experimental Treatments", the period of January through June is the critical period for moisture, it is of interest to note the yield results of the four years with respect to rainfall during this period. In Table 18 certain calculations are presented. The increased yields for irrigation treatments appear to be related to the amount of rainfall for this critical period of January through June. No better fit was found for other rainfall periods. Furthermore, it would follow logical reasoning that any deficiencies of moisture at the time of fruit set and early sizing would result in crop reductions.

In considering the figures in Table 18 the factor of distribution

TABLE 18

Relationship between Fruit Production and Rainfall during Period January through June

	Season 1951-52	1952-53	1953-54	1954-55
Boxes per tree				
Treatment A	13.68	8.98	16.72	10.58
Treatment B	15.88	10.48	17.98	12.55
Treatment C	16.82	11.35	18.36	13.90
Rainfall in inches, January through June	16.79	21.19	25.38	18.06
Increase in boxes per tree				
Treatment B over Treatment A	2.20	1.50	1.26	1.97
Treatment C over Treatment A	3.14	2.37	1.52	2.32
Percent of increase				
Treatment B over Treatment A	16.1	16.7	7.5	18.6
Treatment C over Treatment A	23.0	26.4	9.7	21.9
Number of irrigation applications				
Treatment A	0	0	0	0
Treatment B	1	1	0	1
Treatment C	4	2	2	3

of rainfall must be taken into account. Deficits during the early part of the period may be overcome by excesses during the latter portion, or the reverse condition may obtain. Intensity of rainfall is also of importance. A number of light rains extended over a period may not total as many inches of water as may fall in one 24-hour period in Florida. Certainly the first pattern may at times be superior in crop-producing effect to the second. While certain conclusions may be drawn from the present studies, further study of rainfall patterns in Florida should be made.

2. Size

During the season 1951-52 random fruit from the treatment plots in Block I were tabulated for size and recorded in inches of cross-sectional diameter. No distinction was made for clustered or singly-held fruit, and fruit was included from all sides of the trees. These measurements are shown in Table 19.

TABLE 19

Size of Fruit, in Inches, for Treatments in Block I during Season 1951-52

Date	Treatment A		Treatment B		Treatment C	
	Number Fruit	Average Size	Number Fruit	Average Size	Number Fruit	Average Size
November 10, 1951	722	3.56	783	3.61	421	3.74
November 24, 1951	205	3.67	200	3.73	215	3.80
December 8, 1951	199	3.74	199	3.80	200	4.16
March 1, 1952	127	3.80	115	3.78	104	3.91

A complete tabulation was made on November 24, 1951, using approximately 200 fruits, borne singly or in clusters, randomly selected and sized from the buffered trees in each plot. The averages for the treatments were as follows: Treatment A - 3.66 inches, Treatment B - 3.75 inches, and Treatment C - 3.79 inches, with an F value of 4.788.

During the remaining crop seasons, size studies were made only of fruit held singly. During the seasons 1952-53 and 1953-54 such fruit was from the south-east corner of the buffered trees, but during the season 1954-55, due to the hedging operation, fruit was randomly selected from the east side of the same buffered trees. These data are given in Table 20.

TABLE 20

Cross-Sectional Diameter of Fruit for the Various Treatments
Seasons: 1952-53, 1953-54, 1954-55
(expressed in inches)

Season	Date	Treatment A	Treatment B	Treatment C	F value
1952-53	December 20, 1952	4.08	4.20	4.14	0.736
1953-54	July 3, 1953	3.02	3.01	3.02	0.074
	July 18, 1953	3.18	3.16	3.14	1.162
1954-55	June 26, 1954	2.92	3.03	3.05	2.472
	July 24, 1954	3.36	3.39	3.41	1.632
	November 6, 1954	4.09	4.04	4.06	0.253

Any increase in size of the individual fruit may be highly desirable, provided that the fruits do not become puffy or develop extremely large sizes unsatisfactory for commercial handling. With Marsh grapefruit on Rough lemon rootstock the individual fruits are sometimes too small (with excessive numbers of size 96 and smaller) for good commercial handling in the fresh fruit trade, but more often they are within the size groups (64, 70, 80, and 96) which find desirable markets. Large sizes (54 and larger) are often not in market demand. As the number of fruits borne by a particular tree increases, there is a tendency for the size of the individual fruits to decrease. This tendency appears to be very marked in citrus fruits.

In the season 1951-52 there was an apparent increase in fruit sizes with irrigation, although it did not approach the 95 percent confidence level. Such differences were noted on several inspection dates (Table 19) and continued to be apparent until the fruit was becoming

senile in March. In Table 21 comparisons are shown of fruit size and crop for this season.

TABLE 21

Relationship between Size of Individual Fruit and Size of Crop under Various Treatments for Season 1951-52

	Fruit Size (inches	Crop per tree (boxes)
Treatment A	3.66	13.68
Treatment B	3.75	15.88
Treatment C	3.79	16.82
Increase in size	Percent	Percent
Treatment B over Treatment A	2.5	16.1
Treatment C over Treatment A	3.6	23.0

A study of Table 21 would indicate that a portion of the increased crop was due to increases in size of the individual fruits, but that the greater part of the increase was due to increased numbers of fruit set (or held against droppage) by irrigation. No record was taken of percentage of blossoms which set fruit, or of amount of fruit which dropped during the spring months. No exceptional droppage was noted, however.

During the remaining three seasons, the differences in sizes failed entirely of significance and were of much less magnitude than those found in the season of 1951-52. During the season 1954-55 an apparent increase in fruit size in the irrigated plots was found in June. It became less noticeable in July and was practically lost in November. The larger sizes of the fruit for the season 1952-53 can be attributed to the smaller crop of that year. In 1954-55 larger sizes were

developed in all treatments, apparently due to the hedging operation of April, 1954, which increased the root/top ratio of the tree. An undetermined amount of fruit was removed in this hedging operation. As a commercial practice it would have been more satisfactory to have completed the hedging operation prior to the blooming period.

The size studies appear to show that increased yields due to irrigation must be obtained chiefly from either a greater number of fruit set or a lesser number of drops throughout the growing season. The latter appears to be the case with the present research. Furthermore, the size of the individual fruits is definitely related to the leaf area per fruit.

No particular benefit from increase in size of individual fruits would seem to have been derived from irrigation practices during this study. This conclusion is justified by the fact that no correlations can be drawn between size of individual fruits and amount of rainfall, either for the assumed critical period of January through June, or the entire year. The differences in fruit sizes between treatments obtained during the season 1951-52, the season of least spring rainfall, leads to the possibility of influences in this direction during years of severe drought.

3. Juice Content

As a general rule irrigation treatments tended to show an influence in the direction of increased juice content, although in no case were differences of statistical significance shown. Often the juice content is increased immediately following an irrigation operation, only to

become less noticeable as the season progresses. When the entire data for juice content were analyzed a significant F value was obtained although the differences have no practical value to the grower. In Table 22 is given the results of treatments on juice content.

TABLE 22

Content of Juice per Fruit under Various Treatments for the Four Seasons (in ml.)

Season	Date	Fruit Size	Treatment A	Treatment B	Treatment C	F value
1951-52	December 8, 1951	96	159.50	166.75	170.50	2.286
1952-53	November 8, 1952	80	193.25	201.75	209.50	4.008
	December 5, 1952	80	222.00	232.50	221.00	2.621
1953-54	September 12, 1953	96	144.25	148.00	153.50	4.593
	October 26, 1953[a]	80	211.75	211.75	216.25	0.327
	October 26, 1953[a]	80	226.50	220.25	232.25	1.560
	November 21, 1953	96	187.50	189.50	191.25	0.065
1954-55	September 25, 1954	80	183.75	185.50	186.75	0.109
	September 25, 1954	96	176.25	181.50	179.00	0.325
	October 9, 1954	80	193.00	196.00	193.25	0.161
	October 23, 1954	64	283.50	288.50	283.50	0.240
	November 20, 1954	70	249.75	249.00	243.75	0.290

[a] Variations in juice content between tests on this date due to method of extraction by operators.

The juice content varied widely between dates of sampling. A portion of this variation was due to the fact that fruit was of different sizes on various dates. Furthermore, the juice content increases during the fall months as the fruit reaches its prime eating condition.

Although there is a definite trend toward increased juice content as the result of irrigation, the commercial value of such increases is highly doubtful, especially in view of the decreased percentage of total

soluble solids found with irrigation treatments. Juice content of Florida grapefruit normally runs within a satisfactory range from the standpoint of maturity, while the percentage of total soluble solids is often the determining factor between good fruit and poor fruit from the market standpoint.

4. Soluble Solids

The percentages of total soluble solids were determined by the use of the Brix hydrometer, while calculations of pounds of total soluble solids per box were derived from formulae given under "The Methods of Data Collection and Analysis." These data are reported in Table 23.

The percentage of soluble solids in the juice was in every case reduced by irrigation applications. The sensitiveness of this characteristic reduction is shown in the fact that the highest total soluble solids (in percent) was found to be present in the year of least rainfall from January through June, coupled with the fact that further additions of water each brought about influences toward further reductions. This reduction of soluble solids is probably the most characteristic result of irrigation practices.

Sites (35) called attention to two high-solids years (1940-41, and 1942-43) and noted that these years were characterized by unusually low rainfall during the months of June, July, August, and September. Sites et al. (36) showed the trend toward lower solids on a percentage basis to exist as a result of irrigation practices and thought that it might be a simple dilution factor based upon increased juice volumes occurring with irrigation. Voorhees et al. (45) noted a decrease in soluble solids

TABLE 23

Content of Soluble Solids in Marsh Grapefruit under Various Treatments

Season	Date	Fruit Size	Total Soluble Solids as Percent by Weight of Juice: Treatment A	B	C	F value	LSD .05	.01	Pounds of Total Soluble Solids per Standard Box of 1-3/5 Bushel: Treatment A	B	C
1951-52	December 8, 1951	96	9.81	9.49	8.88	146.210**	0.14	0.21	3.42	3.46	3.31
1952-53	November 8, 1952	80	9.40	8.91	8.60	22.908**	0.31	0.47	3.31	3.27	3.27
	December 5, 1952	80	9.36	8.94	8.72	10.603*	0.34		3.78	3.78	3.50
1953-54	September 12, 1953	96	8.01	8.01	7.59	12.207**	0.24	0.36	2.51	2.58	2.53
	October 26, 1953[a]	80	8.03	8.05	7.78	5.100			3.08	3.09	3.04
	October 26, 1953[a]	80	8.25	8.11	7.90	2.755			3.39	3.24	3.32
	November 21, 1953	96	7.76	7.77	7.52	2.954			3.16	3.20	3.12
1954-55	September 25, 1954	80	8.54	8.16	7.86	6.877*	0.46		2.85	2.74	2.66
	September 25, 1954	96	8.36	8.10	7.72	10.717*	0.34		3.21	3.20	3.00
	October 9, 1954	80	8.54	8.27	7.84	15.852**	0.24	0.37	2.99	2.94	2.74
	October 23, 1954	64	8.50	8.25	7.86	14.221**	0.30	0.45	3.50	3.45	3.23
	November 20, 1954	70	8.63	8.48	7.98	13.292**	0.34	0.52	3.44	3.35	3.08

[a] The tests of soluble solids were run by the same operator, but juicing in each case was handled by a different person. In the second test a greater volume of juice was obtained, and it is felt that the higher solids content was due to suspended matter in the juice through the attempt of this operator to extract the maximum juice from the fruit.

in Valencias under irrigation treatment, accompanied by little effect on ratio and Vitamin C content.

It should be noted that during the season 1953-54, during which Treatment B plots received no supplemental water, the percentage of soluble solids in three of the maturity tests showed approximately equivalent values for both Treatment A and Treatment B. Furthermore, it was during this same season, with rainfall from January through June of 25.38 inches, that the differences in percentages of soluble solids between treatments were not maintained at a significant level.

In Table 24 are summarized the data from tests which were run at approximately the same time during each of the four years of the study. The greatest influence in reduction of solids is related to those years with the least spring rainfall, years when the crop response from irrigation would be the greatest. Each increment of supplemental water appears to have its individual response. This factor has seemed the greatest argument against the use of irrigation when not entirely necessary from the standpoint of fruit droppage or tree health.

A regression correlation of percentage of soluble solids on the amount of water in inches applied either through rainfall or irrigation was run on the figures from Table 24. With 10 d.f., an r value of -0.7532** was obtained. The regression equation assumes the form:

$$Y = 11.9798 - 0.1457X$$

where Y is the expected total soluble solids in percent and X is the amount of water applied to the grove in inches during the period January through June either through rainfall or irrigation. There is a definite

TABLE 24

Influence of Rainfall and Supplemental Irrigation on Percentage of Total Soluble Solids

	Date of Maturity Test			
	12/8/51	12/5/52	11/21/53	11/20/54
Fruit Size	96	80	96	70
Percentage of Soluble Solids				
Treatment A	9.81	9.36	7.76	8.68
Treatment B	9.49	8.94	7.77	8.48
Treatment C	8.88	8.72	7.52	7.98
Statistical significance	**	*	n.s.	**
Rainfall in inches January through June	16.79	21.19	25.38	18.06
Rainfall plus irrigation in inches January through June				
Treatment A	16.79	21.19	25.38	18.06
Treatment B	19.29	23.69	25.38	20.56
Treatment C	24.29	26.19	30.38	25.56
Reduction in percentage of solids				
Treatment B over Treatment A	.32	.42	.00	.20
Treatment C over Treatment A	.93	.62	.24	.66

relationship between available moisture and percentage of soluble solids in the juice of the fruit.

Regression correlations of percentage of soluble solids on juice content were run on individual maturity tests. Significant r values were obtained, indicating that a portion of this reduction is due to dilution with increased juice content of fruit. However, some portion is due to a factor or factors which impede the development of the soluble solids, since as shown in Table 23, fruit of similar size but produced with

supplemental water contains less total soluble solids per box than does fruit with no irrigation treatment.

Attention should be called to the seriousness of any dilution of soluble solids, since any delay in building up the solids during the season or any interruption of their reaching maximum percentage values retards the date of legal maturity and further reduces the value of the fruit for the canning and concentrating industries.

Although the percentage of total soluble solids appeared to be decreased by the irrigation treatments, there was a tendency toward higher juice contents. With a trend in the industry toward the purchase of fruit on the basis of pounds of total soluble solids, it was felt advisable to calculate the pounds of total soluble solids per box of fruit. The figures are given in Table 23. The general trend was toward a reduction in the total solids per box.

Two years might be compared. In the season 1953-54, with 25.38 inches of rainfall during the period January through June, the pounds of solids per box were as follows: Treatment A - 3.04, Treatment B - 3.03, and Treatment C - 3.00. Analysis showed no statistically significant differences. However, in the season 1954-55, with 18.06 inches of rainfall in the January-June period, the pounds of solids were as follows: Treatment A - 3.20, Treatment B - 3.14, and Treatment C - 2.94. Irrigation treatments reduced the amounts of solids per box and the differences were of high significance with an F value of 49.556.

These data show that, although a dilution effect does lower the percentage of soluble solids under irrigation, at the same time the

fruit produces a less total amount of these solids. It is also apparent that the greatest amounts of solids are developed under low rainfall conditions.

5. Acid Content

The percentages of anhydrous citric acid were determined by titration. Calculations of pounds of acid per box were made with use of formulas set forth under "The Methods of Data Collection and Analysis". These data are reported in Table 25.

Applications of supplemental water had the effect of reducing the percentage of anhydrous citric acid. Such a reduction would have had an influence in bringing about earlier legal maturity; it certainly had no detrimental effect on the palatability of the fruit since grapefruit grown under Florida conditions normally has an excess acidity. The greatest differences between treatments occurred during the year 1951-52 under low January-June rainfall, while the least differences were found during the season 1953-54, with 25.38 inches of rainfall during this same period.

Regression correlations of percentage of titratable acid on juice content of the fruit run on the data of December 8, 1951 and November 8, 1952 failed to reveal significant r values. It appears that there may be a certain dilution effect, but that other effects of low or high rainfall upon percentage of citric acid must also be present. Such effects were not as constant as were the effects on percentage of soluble solids.

Any decrease in the acid content of Florida grapefruit would make

TABLE 25

Content of Anhydrous Citris Acid in Marsh Grapefruit under Various Treatments

Season	Date	Fruit Size	Total Anhydrous Citric Acid as Percent by Weight of Juice			F value	Pounds of Anhydrous Citric Acid per Standard Box of 1-3/5 Bushel		
			Treatment				Treatment		
			A	B	C		A	B	C
1951-52	December 8, 1951	96	1.43	1.37	1.26	10.667*	0.50	0.50	0.47
1952-53	November 8, 1952	80	1.61	1.55	1.48	3.059	0.57	0.57	0.56
	December 5, 1952	80	1.51	1.40	1.40	4.053	0.61	0.59	0.56
1953-54	September 12, 1953	96	1.46	1.43	1.43	1.900	0.46	0.46	0.48
	October 26, 1953	80	1.26	1.22	1.22	0.434	0.48	0.47	0.48
	October 26, 1953	80	1.18	1.19	1.19	0.059	0.48	0.47	0.50
	November 21, 1953	96	1.20	1.16	1.15	1.333	0.49	0.48	0.48
1954-55	September 25, 1954	80	1.51	1.40	1.42	5.769*	0.50	0.47	0.48
	September 25, 1954	96	1.48	1.45	1.43	4.917	0.57	0.57	0.55
	October 9, 1954	80	1.42	1.34	1.36	2.631	0.50	0.48	0.48
	October 23, 1954	64	1.36	1.30	1.27	4.239	0.56	0.54	0.52
	November 30, 1954	70	1.37	1.34	1.28	3.024	0.54	0.53	0.49

for a more palatable fruit (provided that the soluble solids content was held constant). As with total solids, less citric acid appears to be developed in grapefruit produced with supplemental water than in that fruit dependent only upon natural rainfall, if deficient. Calculations of acid content as total per box indicate that the increases in soil moisture through irrigation practices have an influence, as is shown in Table 25. In the 1953-54 season of high spring rainfall the pounds of acid per box were as follows: Treatment A - 0.4775, Treatment B - 0.4700, and Treatment C - 0.4850, the differences being without statistical significance. With lower rainfall in the spring of 1954-55 the pounds of acid per box were as follows: Treatment A - 0.534, Treatment B - 0.518, and Treatment C - 0.504, with an F value of 10.454** for the differences.

As with soluble solids, a dilution effect of increased juice volume has a tendency to decrease the percentage of anhydrous citric acid; but there is a further effect of lack of development of the acid under either supplemental water or high spring rainfall.

6. Maturity Ratio

The ratio of the percentage of total soluble solids to that of anhydrous citric acid (the solid/acid ratio) is not in itself a good index of the taste of the fruit. Nevertheless, since this ratio does enter into the legal maturity standards for citrus, the results obtained during the course of study are given in Table 26.

The effect of irrigation treatments appears to present a trend toward a lowering of the ratio. However, the differences are slight and

TABLE 26

Maturity Ratios of Marsh Grapefruit under Various Treatments

Season	Date of Test	Fruit Size	Treatment A	Treatment B	Treatment C	F value
1951-52	December 8, 1951	96	6.89	6.97	7.05	0.328
1952-53	November 8, 1952	80	5.85	5.75	5.80	0.143
	December 5, 1952	80	6.22	6.41	6.22	0.758
1953-54	September 12, 1953	96	5.46	5.62	5.32	9.242*
	October 26, 1953[1]	80	6.44	6.64	6.20	1.334
	October 26, 1953[1]	80	7.00	6.82	6.56	1.603
	November 21, 1953	96	6.48	6.66	6.54	0.835
1954-55	September 25, 1954	80	5.68	5.82	5.55	2.552
	September 25, 1954	96	5.64	5.58	5.42	3.366
	October 9, 1954	80	6.02	6.19	5.78	2.564
	October 23, 1954	64	6.27	6.34	6.20	0.734
	November 29, 1954	70	6.36	6.35	6.23	0.529

[1]The second test of this date was highly influenced by the higher percentage of soluble solids apparently resulting from excessive juice extraction by the operator.

of no statistical significance. Any practice which tends to reduce this ratio is to be deprecated under Florida conditions, for the ability to make a passing ratio by legal standards for grapefruit is difficult at best. The lower ratio results in a more acid-tasting fruit, while a higher ratio tends to be sweeter and more acceptable to the average palate.

The lowering of the ratio resulted from the greater reduction in percentage of soluble solids than in percentage of titratable acidity. Influences of various cultural practices upon this ratio are regularly observed more directly as influences upon the component parts setting

up such a ratio. With irrigation the greatest influence is displayed on the soluble solids content of the fruit.

V. CONCLUSIONS AND SUMMARY

A. Practical Conclusions

1. Effect of Irrigation on Yield (boxes/tree).

Irrigation increases the yield in years of low rainfall, i.e., less than 20 inches during the January-June period. In "wet" springs (more than 20 inches of rainfall) irrigation does not increase the crop sufficiently to pay for its cost.

2. Effect of Irrigation on Percentage of Soluble Solids and Total Solids per Box.

The percentage of solids decreases with irrigation. Each additional increment of water produces further decreases. The total amount of solids in pounds per box decreases, although, due to the increase in number of boxes per tree, the total amount of solids in pounds per tree shows a slight increase.

3. Effect of Irrigation on Percentage of Acid and Total Acid.

Irrigation decreases the percentage of acid in all seasons. While the influence on total acid is less pronounced than that on total solids, it can be said that the total acid decreases. An influence of this nature would in itself be of value in improving the marketability of the crop were it not correlated with the greater decrease in solids.

4. Effect of Irrigation on size of Grapefruit.

Irrigation increases the size of the fruit only in dry seasons. In wet seasons the effect of irrigation on the size of the individual

fruits is negligible.

5. Effect of Irrigation on Juice Content.

The juice content is only slightly increased in all seasons. Unfortunately the increases are of little or no practical importance due to the much greater influence of summer rains on juice content of Florida grapefruit.

6. Effect on Ratio (Solids/Acid).

The ratio of soluble solids to acid becomes more unfavorable with irrigation because the percentage of solids decreases to a greater extent than does the percentage of citric acid.

7. Timing of Irrigation.

Soil tests for moisture proved unsatisfactory as a guide for timing irrigation treatments due to the very large number of samples required. Leaf moisture determinations were also found to be unsatisfactory. For the practical grower "temporary wilt" is still the best guide for timing applications. Grove observations should be supplemented with studies of current rainfall records.

8. Frequency of Irrigation.

With the $2\frac{1}{2}$ acre-inches per application, no practical differences in yield were obtained if more applications were made than necessary to relieve temporary wilt. Nevertheless, there are indications in the results of the present researches pointing to the profitableness of operations based on anticipated tree wilt, thereby allowing a safety factor

in the case of large-acreage operations.

9. Economics of Irrigation.

These researches show that only in dry springs (less than 20 inches of rainfall in the period January through June) does the judicious use of irrigation equipment pay in increased boxes per tree. In wet or normal seasons an unwise use of irrigation may retard maturity as defined by state law and bring about a loss of palatability and marketability of the fruit.

10. This study dealt with 25- to 30-year-old Marsh grapefruit on Rough lemon rootstock on Lakeland fine sand. The results in no way apply to the use of supplemental water on young or non-bearing trees, or on bearing trees on poorly-drained soils.

B. Summary

1. Field irrigation studies were conducted on Lakeland fine sand planted to Marsh grapefruit on Rough lemon rootstock over four crop years. A randomized block design with four replications was set up to study three levels of supplemental irrigation: none, sufficient to relieve temporary wilt, and sufficient to assure available soil moisture at all times during the spring months.

2. Statistical studies of rainfall records in Florida showed that, while there are significant differences between months and years, little differences can be found between stations within an area of 100-mile diameter over an entire season in central Florida.

3. Soil moisture determinations, taken over the four years, showed the influence of irrigation treatments, but at no time was it possible to obtain a sufficient number of samples to establish any value which could be used as an indication of the need for irrigation.

4. Statistical studies of moisture content in the soil to a depth of four feet showed that there is a correlation in soil moisture between depths within this range. Substantiating evidence is drawn from the work of Koo (17).

5. Supplemental irrigation increases the yield in boxes per tree, but only in years of light spring rainfall are such increases of statistical significance, or of practical value to the grower.

6. The percentage of total soluble solids in the juice is decreased with irrigation. Such decreases are correlated with increases in juice content, corroborating the conclusions of Sites et al. (36) that such decreases are due primarily to dilution. There is shown also, however, a decrease in the pounds of total soluble solids per box.

7. With irrigation there is a decrease in the percentage of anhydrous citric acid as well as in the pounds of acid per box. The influence on acids was not as great as that on solids, and no correlation could be shown with increases in juice content.

8. There is an increase in the size of individual fruits with supplemental irrigation although this effect is marked only in years of low spring rainfall. Under average Florida conditions such increases appear to be of no practical importance.

9. The increase in juice content found under irrigation treatments is

of statistical value but of little commercial importance to the Florida grower.

10. The influence of irrigation on the solids/acid ratio is without statistical significance. The slight tendency toward a lowered ratio, however, is disadvantageous from the standpoint of legal maturity.

11. All of the above-noted trends were increased under irrigation aimed at maintaining soil moisture at an available level at all times, when compared with treatments applied simply to relieve temporary wilt in the trees. No accrued values could be drawn from increased applications over those sufficient to relieve such temporary wilt. In fact, the influence toward decreases in percentage of soluble solids militates against the practice of regular applications of water provided the trees are not allowed to become wilted.

12. The use of irrigation as a regular production practice under the conditions of the study is of doubtful economic value except in those years, such as 1951-52 and 1954-55, with low spring rainfall.

13. No absolutely satisfactory index was found by which to determine the timing of irrigation applications. The combination of observations of tree wilt and records of rainfall appears to offer the best guide for field conditions at the present time.

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BIOGRAPHICAL ITEMS

Louis William Ziegler was born on May 17, 1907, at Buffalo, New York. Moving to Florida in 1924, his secondary education was completed at Orlando. With the help of an agricultural scholarship awarded by Orange County, he received the degree of Bachelor of Science in Agriculture from the University of Florida in 1930.

For a year he served as Assistant Entomologist with the Florida Agricultural Experiment Station prior to accepting a position as Research Entomologist with the California Spray-Chemical Corporation. During the years 1931-32 he also operated the Crypt Laboratories, a biological control unit, at Orlando. In 1935 he began field service work with the Jackson Grain Company, Tampa. From 1937 to 1939 a private citrus production service was conducted, serving a number of growers and associations throughout the state. He also served as Production Manager for Auburndale Citrus Growers Association.

He held the position of Production Manager for Holly Hill Fruit Products, Inc., at Davenport, Florida, from 1939 to 1947. In the latter year he became affiliated with the Haines City Citrus Growers Association, leaving in September of the same year to accept an assistant professorship in Horticulture at the University of Florida.

He received the degree of Master of Science in Agriculture at the University of Florida in June, 1950, and continued studies leading to the degree of Doctor of Philosophy.

He currently holds a position as Associate Professor of Horticulture at the University of Florida.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of the committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June 6, 1955

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